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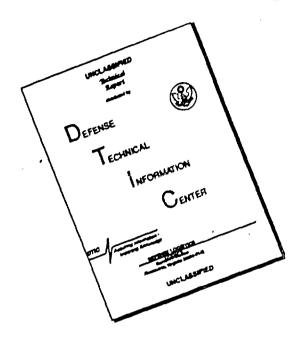
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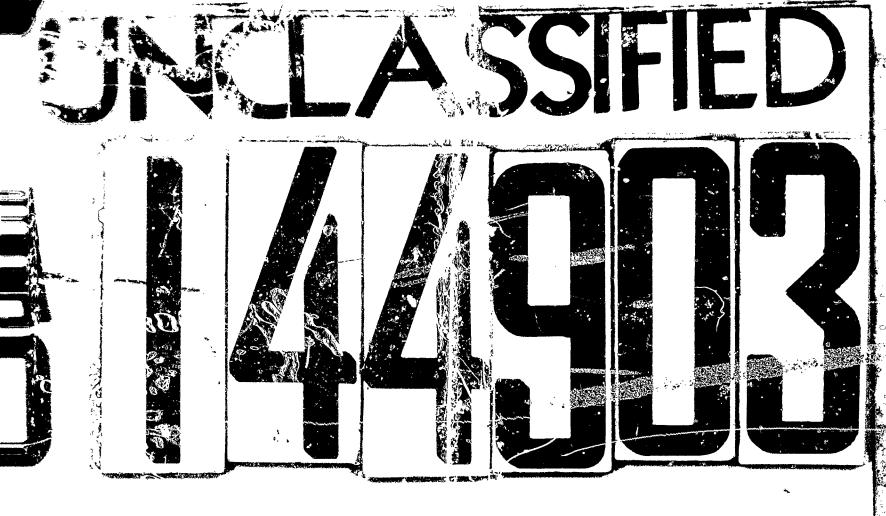
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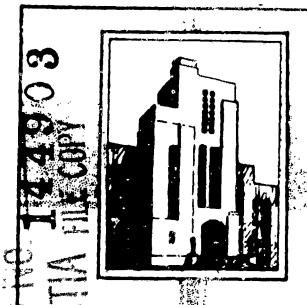
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# DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

THE IDEAL EFFICIENCY OF OPTIMUM
PROPULLERS HAVING FINITE HUBS
AND FINITE NUMBERS OF BLADES

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**AERODYNAMICS** 

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STRUCTURAL MECHANICS

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HYTRODYNAMICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

APPLIED MATHEMATICS

July 1957

Report No. 1148

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AND FINITE MUMBERS OF PLACES

by

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HYDEODYNAMICS LABORATORY
RESEARCH AND DEVELOPMENT REFULT

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# Notation

| c <sub>T1</sub>  | Ideal (non-viscous) thrust coefficient                                   |
|------------------|--|
| h                | Subscript denoting finite hub  |
| K <sup>(Z)</sup> | Integral defined by equation (2)   |
| r                | Section radius   |
| R                | Proreller tip radius   |
| X = _T.          | Nondimensional section radius  |
| X <sub>n</sub>   | Non-dimensional but radius   |
| 2                | Number of Blades   |
| Pi               | Hydrodynamic pitch angle   |
| n                | Ideal efficiency   |
|                  | Advance coefficient  |
| $\lambda_{i}$    | Induced advance coefficient $(=\frac{\lambda}{\eta_i} = x \tan \beta_i)$ |
| K                | = ε(λ, z,x,xh) "Goldstein Fector" or                                     |
|                  | "Circulation Distribution Factor" from reference (8)                     |

#### Abstract

The ideal (non-viscous) thrust coefficient  $C_{T_1}$  related to a range of ideal efficiencies ( $\eta_i$ ) and a range of advance coefficients ( $\lambda$ ) is calculated for propellers having 3,4,5 and 6 blades and having hubs whose diameters are 0.2, 0.3 and 0.4 of the propeller diameter.

#### Introduction

The relationships between ideal (non-viscous) thrust coefficient  $C_{T_1}$ , ideal efficiency  $\eta_i$  and advance coefficient  $\lambda$  for probellers having a finite number of blades but zero hub diameter were determined by Kramer after suitably transforming equations (8) and (11) of Lösch for finite blade number. The results obtained were based on Goldstein's solution of the potential problem, recalculated by Lock, and Yeatman and Kramer, himself, and extended by Kramer for large values of  $\lambda_i$ .

When Lerbs published a proveller design method using "induction factors," it became possible to compare theoretically the circulation distributions for lightly and moderately loaded procellers. When, as a result of

References are listed on page 5

this comparison, it was seen that the condition of normality for lightly loaded propellers could be applied to moderately loaded propellers with good accuracy, "it was then deemed necessary to determine the Goldstein Factor by more accurate methods than had previously been used, particularly for sections near the tip and for large advance ratios." This was done by Tachmindji and Milam.

Noting the increasing use of propellers with relatively large hubs, Tschmindji<sup>7</sup> formulated and solved the potential problem for propellers with finite hub diameters. Numerical evaluations are presented by Tachmindji and Milam.<sup>8</sup>

Herein are given relationships between ideal (nonviscous) thrust coefficient  $C_{T_1}$ , ideal efficiency  $\eta_i$  (=0.50, 0.60, 0.70, 0.80, 0.85, 0.90, 0.95, 0.97, 0.99) and  $\lambda = \lambda_i$   $\eta_i$ . Kramer's work is thus extended for propellers having finite hubs.

#### Method of Computation

The basic equation for the computation is Kramer's equation (1.1) (notation is changed to agree with that in use at the David Taylor Model Basin):

$$c_{T_1} = \frac{8(1-\eta_1)}{\eta_1} K_{31}^{(Z)} + \frac{8(1-\eta_1)^2}{\eta_2} K_{52}^{(Z)}$$
 (1)

 $\mathbf{x}^{(Z)} = \int_{\mathbf{A}_1^2 + \mathbf{x}^2)^n}^{\mathbf{x}} d\mathbf{x}$ (2)

where C<sub>Ti</sub> = ideal thrust coefficient

\[ \mu = ideal efficiency
\]

 $\mathbf{E} = \mathbf{E} (\lambda_1, \mathbf{Z}, \mathbf{X}, \mathbf{X}_h) = \text{"Goldstein}$ Function" or "Circulation Distribution Factor" from reference (8)

 $\lambda_i = x \tan \beta_i = \frac{\lambda_i}{\lambda_i}$ 

β<sub>1</sub> = hydrodynamic mitch engle
λ = advance ratio

Z = number of blades

 $X = \frac{r}{R}$  nondimensional section radius

h = subscript denoting finite hub

The integrations of  $K^{(Z)}$  were performed using a mn desk computer and Simpson's first and second rules.

#### Presentation of Legults

Curves relating  $C_{T_1}$ ,  $\eta_i$  and  $\lambda$  for 3, 4, 5 and 6 bladed propellers having 0.2, 0.3 and 0.4 hub diameter ratios are given in Figures 1-1 Appendix B. In addition, curves taken from Kramer's curves for zero hub and 4 bladed are plotted on Figure 2 in order to show a comparison with propellers having finite hubs.

For more convenient use in interpolating for values of  $\lambda_i$  and  $X_h$  between those given, Tables 1-4, Appendix A, give values of  $C_{T_i}$  as a function of Z,  $\lambda_i$ ,  $\eta_i$  and  $X_h$ .

The results presented are considered accurate within one in the third significant figure throughout the range covered.

#### References

- Kramer, K. N., "Induzierte Wirkungsgrade von Best-Luftschrauben endlicher Blattzahl," Luftfahrtforschung, Vol. 15, no. 7, July 6, 1038.
- 2. Losch, F., "Über die Berechnung des induzierten Wirkungsgrades stark belosteter Luftschrauben unendlicher Blattzahl," Luftfahrtforschung, Vol. 15, no. 7, July 6, 1938.
- 3. Goldstein, E., "On the Vortex Theory of Screw Propellers," Proceedings Royal Society, Vol. 123A, 1929.
- 4. Lock, C. M. H., and Weatman, D. M., "Tables for Use in an Improved Method of Airscrew Strip Theory Calculation," R. and M. No. 1674, British A.R.C., 1035.
- Lerbs, H. W., "Moderately Loaded Propellers with a Finite Number of Blades and an Arbitrary Distribution of Circulation," Trans. SNAME, 1952.
- 6. Tachmindji, A. J., and Milar, A. B., "The Calculation of Goldstein Factors for Three, Four, Five and Six Bladed Propellers," DTMB Report No. 1034, March 1956.
- 7. Tachmindji, A. J., "The Potential Problem of the Optimum Propeller with Finite Hub", DTMB Report No. 1051, August 1956, and International Shipbuilding Progress, November 1956.
- 8. Tachmindji, A. J., and Milam, A. B., "The Calculation of the Circulation Distribution for Propellers with Finite Hub Having Three, Four, Five and Six Blades," DTMR Report No. 1141, June 1957.

# Appendix A

Tables of  $C_T = \eta_i = 1/\lambda_i$  for 3,4,5 and 6 hladed propellers

Table I

Ideal Thrust Coefficient, CT4, for THREE-BLADED Propellers

|      | Ideal  | Thrust Coef | ficient, C <sub>T</sub> | 1, for THRE    | B-BLADED Pr | opellers |         |
|------|--------|-------------|-------------------------|----------------|-------------|----------|---------|
| 水水   | 3.0    | 3.5         | 4.0                     | 4.5            | 5.0         | 5.5      | 6.^     |
|      |        |             | $\mathbf{x_h}$          | = 0.2          |             |          |         |
| 0.50 | 3.3514 | 3.8587      | 4.2842                  | 4.6338         | 4.9356      | 5.1848   | 5.3954  |
| 0.60 | 1.9089 | 2.1860      | 2.4177                  | 2.6104         | 2.7715      | 2.9066   | 3.0208  |
| 0.70 | 1.0777 | 1,2278      | 1.3529                  | 1.4567         | 1.5434      | 1.6160   | 1.5774  |
| 0.80 | 0.5632 | 0.6396      | 0.7011                  | 0.7529         | 0.7961      | 0.8322   | 0.8627  |
| 0.85 | 0.3786 | 0.4282      | C.4693                  | 0.5033         | C.5316      | 0.5553   | · .5753 |
| 0.40 | 0.2278 | 0.2570      | 6.2812                  | 6.3011         | 1.3178      | 0.3317   | r.3434  |
| 0.95 | 0.1034 | 0.1364      | 0.1271                  | 0.1360         | 0.1433      | 0.1495   | 1.15/.7 |
| 0.97 | 0.0598 | 0.0672      | 0.0734                  | 0.0784         | ^.0827      | 0.0862   | 1.1892  |
| 0.99 | 0.0192 | 0.0216      | 0.0236                  | 0.0252         | 0.0265      | 0.0276   | 0.0236  |
|      |        |             | Xi. i                   | = 0.3          |             |          |         |
|      |        |             | ~n                      |                |             |          |         |
| 0.50 | 3.0441 | 3.5161      | 3.9152                  | 4.2510         | 4.5316      | 4.7690   | 4.9696  |
| 0.60 | 1.7296 | 1.9876      | 2,2053                  | 2.3882         | 2.5409      | 2.6700   | 2:7792  |
| 0.70 | 0.9742 | 1.1140      | 1.2318                  | 1.3306         | 1.4130      | 1.4826   | 1.5414  |
| 0.80 | 0,5060 | 0.5782      | 0.6372                  | <b>∂.6366</b>  | 7278        | 0.7626   | 0.7919  |
| 0.85 | 0.3411 | 0.3873      | 0.4261                  | ^.4536         | 0.4857      | 0.5085   | 0.5278  |
| 0.90 | 0.2050 | 0.2322      | 0.2551                  | 0.2742         | 0.2901      | 0.3035   | 0.3149  |
| 0.95 | 0.0929 | 0.1051      | 0.1152                  | .1237          | 0.1308      | 0.1367   | C.1418  |
| 0.97 | 0.0537 | 0.0607      | 7.765                   | 0.0714         | C.0754      | 0.0788   | 0.0817  |
| 0.99 | C.0173 | 0.0195      | 0.0213                  | 0.0429         | 0.0242      | 0.0252   | 0.0262  |
|      |        |             | X <sub>h</sub> :        | = 0.4.         |             |          |         |
|      |        |             | ••                      |                |             |          |         |
| J.50 | 2.6321 | 3.0563      | 3.4218                  | 3.7291         | 3.9965      | 4.2214   | 4.4142  |
| ი.60 | 1.4917 | 1.7240      | 1.9239                  | 2.0918         | 2.2380      | 2.3608   | 2.4662  |
| 0.70 | 0.8361 | 0.9643      | 1.0727                  | 1.1637         | 1.2429      | 1.3095   | 1.3665  |
| 0.80 | 0.4361 | 0.4995      | 0.5540                  | 7 <b>.5996</b> | c.6394      | 0.6728   | c.7014  |
| 0.85 | 0.4924 | 0.3343      | 0.3702                  | 0.4002         | 0.4264      | C. LLBL  | 0.4673  |
| 0.90 | 0.1755 | 0.2002      | 0.2214                  | 0.2391         | 0.2546      | 0.2675   | c.2786  |
| 0.95 | 0.0795 | 0.0905      | 0.0999                  | 0.1078         | 0.1347      | 0.1204   | r.1254  |
| 0.97 | 0.0459 | 0.0522      | 0.0576                  | 0.0622         | 0.0661      | 0.0694   | 0.0722  |
| 0.99 | 0.0148 | 0.0166      | 0.0185                  | 0.0199         | 0.0212      | 0.0222   | ₹.0231  |

Table II

Ideal Thrust Coefficient, CT., for FCUM-BLADED Propellers

|              | Ineel :          | Infuse Coeff     | ricient, C <sub>T</sub> | , ror rous-      | -BLADED Proj                       | ellers           |                  |
|--------------|------------------|------------------|-------------------------|------------------|------------------------------------|------------------|------------------|
| ni Xi        | 3.0              | 3.5              | 4.0                     | 4.5              | 5.0                                | 5.5              | 6.0              |
|              |                  |                  | ×b ·                    | c.2              |                                    |                  |                  |
| 0.50         | 3.7639           | 4.2684           | 4.6787                  | 5.0142<br>2.8214 | 5 <b>.258</b> 2<br>2 <b>.9</b> 693 | 5.5150<br>3.0915 | 5.7034<br>3.1931 |
| 0.60<br>0.70 | 2.1434<br>1.2098 | 2.4176<br>1.3577 | 2.6401<br>1.4772        | 1.5743           | 1.6534                             | 1.7188           | 1,7730           |
| 0.80         | 0.6322           | 0,7060           | 0.7655                  | 0.8136           | 0.8528                             | C.8351           | 0.9119           |
| 0.85         | 0.4249           | 0.4734           | 0.5124                  | 0.5439           | 0.5695                             | 0.5906           | 0.6061           |
| 0.90         | 0.2556           | 0,2441           | 0.3069                  | 0.3254           | 0.3404                             | 0.3528           | 0.3630           |
| 0.95         | 0.1160           | 0.1278           | 0.1366                  | 0.1469           | C.1535                             | 0.1590           | 0.1635           |
| 0.97         | 0.0673           | 0.0743           | 0.0601                  | 0.0848           | C.0685                             | 0.0917           | 0.0942           |
| 0.99         | 0,0236           | 0.0239           | 0.0257                  | 0.0272           | 0.0284                             | 0.0294           | 0.0302           |
|              |                  |                  | ×h '                    | <b>= 0.3</b>     |                                    |                  |                  |
| 0.50         | 3.4924           | 3.9646           | 4.3505                  | 4.6647           | 4.9212                             | 5.1331           | 5.3117           |
| 0.60         | 1.9836           | 2.2410           | 2.4504                  | 2,6206           | 2.7594                             | 2.8739           | 2,9706           |
| 0.70         | 1.1172           | 1.2560           | 1.3686                  | 1.4600           | 1.5344                             | 1.5959           | 1.6477           |
| 0.80         | 0,5626           | 0.6519           | 0.7060                  | 0.7534           | 0.7903                             | 0.8206           | 0.2465           |
| 0.85         | 0.3912           | 0.4367           | 0.4735                  | 0.5032           | 0.5274                             | 0.5474           | 0.5642           |
| 0.90         | 0.2351           | 0.2618           | 0.2834                  | ( <b>.3009</b>   | 0.3150                             | 0.3267           | 0.3366           |
| 0.95         | 0.1066           | 0.1184           | 0.1260                  | 0.1357           | 0.1420                             | 0.1472           | 0.1515           |
| 0.97         | 0.0636           | 0.0684           | 0.0739                  | 0.0783           | 0.0619                             | 0.0848           | 0.0873           |
| 0,99         | 0.0196           | 0.0220           | 0.0237                  | 0.0251           | 0.0262                             | 0,0272           | 0,0280           |
|              |                  |                  | Mg 1                    | = 0.4            |                                    |                  |                  |
| 0.50         | 3.0961           | 3.5309           | 3.0093                  | 4.1823           | 4.4244                             | 4.6256           | 4.7967           |
| 0.60         | 1.7596           | 1.9917           | 2,1866                  | 2.3461           | 2.4776                             | 2.5869           | 2.6799           |
| 0.70         | 0.9865           | 1.1140           | 1.2193                  | 1.3052           | 1.3760                             | 1.4349           | 1.4850           |
| 0.80         | 0.5133           | 0.5771           | 0.6297                  | 0.6725           | 0.7076                             | 0.7372           | 0.7622           |
| 0.85         | 0.3442           | 0.3662           | 0.4206                  | 0.4489           | 0.4721                             | 0.4914           | 0.5076           |
| 0.90         | 0.2066           | 0.2323           | 0.2516                  | 0.2682           | 0,2618                             | 0.2931           | 0.3028           |
| 0.95         | 0.0936           | 0.1046           | 0.1136                  | 0.1209           | 0.1270                             | 0.1320           | 0.3362           |
| 0.97         | 0.0541           | 0.0004           | 0.0655                  | 0.0697           | 0.0732                             | 0.0760           | 0.0785           |
| 0.99         | 0.0174           | 0.0394           | 0.0230                  | 0.0224           | 0.0235                             | 0.0244           | 0.0252           |

Table III

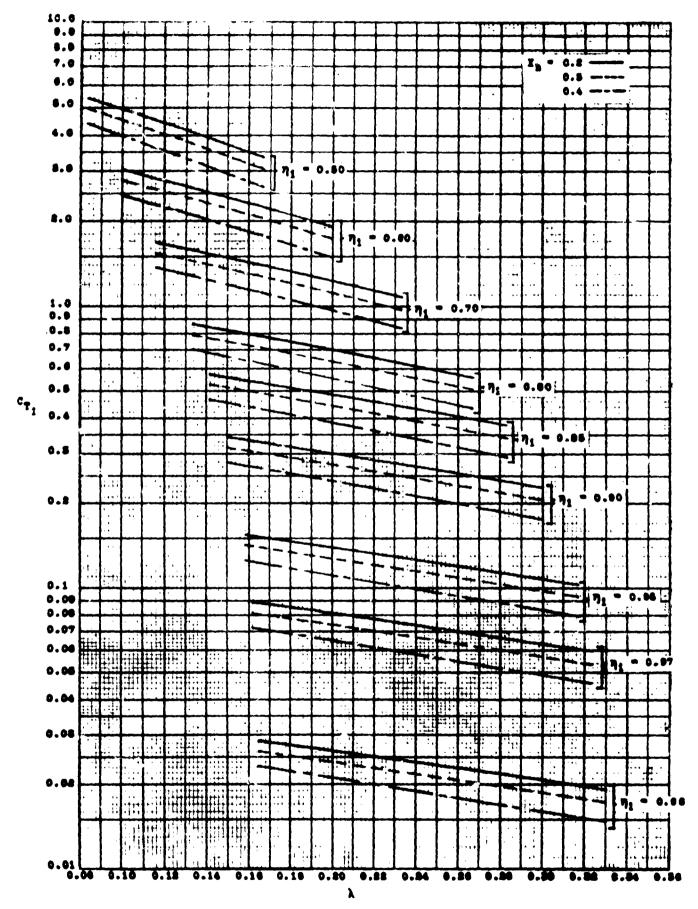
|              | Ideal 1                          | hrust Coeff | icient, C <sub>T</sub> | , for FIVE | BLADED Proj | ællers |                |
|--------------|----------------------------------|-------------|------------------------|------------|-------------|--------|----------------|
| n Ai         | 3.0                              | 3.5         | 4.0                    | 4.5        | 5.0         | 5.5    | 6.0            |
|              |                                  |             | z <sub>b</sub> :       | e 0.2      |             |        |                |
| 0.50         | 4.0250                           | 4.5214      | 4.9182                 | 5.2370     | 5,4954      | 5.7070 | 5.8817         |
| 0.60         | 2.2915                           | 2.5606      | 2.7748                 | 4.9465     | 3.0855      | 3.1991 | 3.2928         |
| 0.70         | 1.2932                           | 1.4377      | 1.5524                 | 1.6440     | 1.7181      | 1.7785 | 1.5283         |
| 0.80         | 6756                             | 0.7475      | 0.8043                 | 0.8496     | 0.8861      | 0.9158 | C.9403         |
| 0.85         | 0.4540                           | 0.5012      | 0.5383                 | C.5679     | 0.5917      | 0.6111 | 0.6271         |
| 0.90         | 0.2731                           | 0.3007      | 0.3225                 | 0.3396     | 0.3537      | 0.3650 | c.3743         |
| 0.95         | 0.1239                           | 0.1362      | 0.1458                 | 0.1534     | C.1595      | 0.1645 | 0.1686         |
| 0.97         | 0.0716                           | 0.0786      | 0.0841                 | 0.0885     | 0.0920      | 0,0948 | 0.0972         |
| 0.99         | 0.0230                           | 0.0253      | 0.0270                 | 0.0284     | 0.0495      | 0.0304 | C. <b>C311</b> |
|              |                                  |             | z <sub>h</sub> :       | = 0.3      |             |        | •              |
| 0.50         | 3.7614                           | 4.2462      | 4.6164                 | 4.9124     | 5.1510      | 5.3456 | 5.5054         |
| 0.60         | 2.1482                           | 2.4001      | 2,6001                 | 2.7597     | 2.8861      | 2.9929 | 3.7788         |
| 0.70         | 1,2098                           | 1.3451      | 1.4522                 | 1.5375     | 1.6060      | 1.6619 | 1.7077         |
| 0.80         | 0.6309                           | 0.6961      | 0.7512                 | 0.7934     | 0.8272      | 0.8547 | 0.8773         |
| 0.85         | 0.4236                           | 0.4676      | 0.5024                 | 0.5299     | 0.5520      | 0,5700 | 0.5847         |
| 0.90         | 0.2545                           | 0.2804      | 0.3007                 | 0.3168     | 0.3297      | 0.3402 | 0.3488         |
| 0.95         | 0.1154                           | 0.1266      | 0.1358                 | 0.1429     | 0.1486      | 0.1533 | 0.1570         |
| 0.97         | 0.0667                           | 0.0732      | 0.0784                 | 0.0824     | 0.0657      | 0.0383 | 0.0905         |
| 0.99         | 0.0214                           | 0.0235      | 0.0252                 | 0.0264     | 0.0275      | 0.0283 | 0 <b>.0290</b> |
|              |                                  |             | *                      | = 0.4      |             |        |                |
| 0.00         | 3.4165                           | 3.8451      | 4.1876                 | 4.4638     | 4,6862      | 4.8678 | 5.0180         |
| 0.50<br>0.60 | 20-00-2                          | 2.1689      | 2.3545                 | 2.5040     | 2.6242      | 2.7223 | 2.8035         |
|              | 1.9362<br>1.0879                 | 1.2132      | 1.3128                 | 1.3930     | 1.4574      | 1.5100 | 1.5535         |
| 0.70         |                                  | 0.6284      | 0.6760                 | 0.7178     | 0.7497      | 0.7758 | 7973           |
| 0.80         | 0.5660                           | 0.4206      | 0.4530                 | 0.4791     | 0.5000      | C.5171 | .5312          |
| 0.45         | 0 <b>.3796</b><br>0 <b>.2279</b> | 0.2519      | 0.2710                 | 0.2862     | 0.4985      | C.3065 | n.3168         |
| 0.90         | 0.1032                           | 0.1139      | r.1223                 | 0.1290     | 0.1345      | r.1369 | 0.1425         |
| 0.95         | 0.0996                           | 0.6572      | 0.0705                 | .0744      | 0.0775      | 0,0800 | 0.0821         |
| 0,97<br>0,99 | 0.0192                           | 0.0211      | 0.0226                 | 0.0239     | 0.0348      | 0.7256 | 0.0263         |

Table IV

|              | Ideal                    | Thrust Coef | ficient, C <sub>T</sub> | , for SIX-       | BLADED Prope | flors    |                 |
|--------------|--------------------------|-------------|-------------------------|------------------|--------------|----------|-----------------|
| MY N         | 3.0                      | 3.5         | 4.0                     | 4.5              | 5.0          | 5.5      | <b>6.</b> 7;    |
|              |                          |             | ×h =                    | 0.2              | -            |          |                 |
| 0.60         | 4.2048                   | 4.6913      | 5.0764                  | 5.3830           | 5.6296       | 5.8298   | 5.9942          |
| 0.50         | 4.3934                   | 2.6564      | 2.8639                  | 3.0285           | 3.1607       | 3.2679   | 3.3558          |
| 0.60         |                          | 1.4914      | 1.6021                  | 1.6897           | 1.7599       | 1.8167   | 1.8632          |
| 0.70         | 1,3505<br>0,7054         | 0.7753      | 0.8300                  | 0.8731           | 0.9076       | 0.9354   | r. <b>958</b> 2 |
| 0.80         | 0.1740                   | 0.5196      | 0.5555                  | C.5836           | 0.6061       | 0.6243   | 0 <b>.6390</b>  |
| 0.85         | ·                        | 0.3139      | 0.3328                  | 0.3492           | 0.3622       | 0.3728   | 0.3814          |
| .0.90        | 0.2 <b>851</b><br>0.1294 | 0.1412      | 0.1504                  | 0.1576           | 0.1634       | r.1680   | 0.1718          |
| 0.95         | 0.0748                   | 0.0616      | 0.0668                  | 0.0909           | 0.0942       | 0.0969   | 0.0990          |
| 0.97         | 0.0240                   | 0.0262      | 0.0279                  | 0.0292           | 0.0302       | 0.0310   | 0.0317          |
| 0 <b>.99</b> | O . MENO                 | 0,000       |                         | •                |              | ٠.       | •               |
|              |                          |             | x <sub>h</sub> :        | • 0.3            |              | •        |                 |
|              |                          |             |                         |                  | £ 20£3       | 5.4794   | 5.6269          |
| 0.50         | 3.9606                   | 4.4350      | 4.7912                  | 5.0731           | 5,2981       | 3.0678   | 3.1467          |
| 0.60         | 2,2612                   | 2,5067      | 2.6965                  | 2.8499           | 2.9706       | 1.7035   | 1.7453          |
| 0.70         | 1.2734                   | 1.4048      | 1.5071                  | 1.5878           | 1.6519       | 0.8761   | 0.8967          |
| 0.80         | 0.6640                   | 0.7291      | 0.7796                  | 0.8193           | 0.8508       | 0.5843   | 0.5976          |
| 0.85         | 0.4458                   | 0.4864      | 0.5234                  | 0.5472           | 0.5678       | 0.3486   | 0.3565          |
| 0.90         | 0.2678                   | 0.2928      | 0.3121                  | 0.3272           | 0.3392       | 0.1571   | 0.1605          |
| 0.95         | 0.1214                   | 0.1325      | 0.1410                  | 0.1476           | 0.1529       | 0.0906   | 0.0925          |
| 0.97         | 0.0702                   | 0.0765      | 0.0813                  | 0.0851           | 0.0681       | 0.0290   | 0.0296          |
| 0.99         | 0.0226                   | 0.0246      | 0.0261                  | 0.0273           | 0.0283       | 0 100 20 | 0,00,0          |
|              |                          |             | 2                       | = 0.4            |              |          |                 |
|              |                          |             |                         | 1 6173           | 4.8542       | 5.0212   | 5.1583          |
| 0.50         | 3,6407                   | 4.0593      | 4.5000                  | 4.6473<br>2.6069 | 2.7183       | 2,8061   | 2,8819          |
| 0.60         | 2.0633                   | 2,2897      | 2.4672                  |                  | 1.5097       | 1.5576   | 1.5969          |
| 0.70         | 1.1593                   | 1,2807      | 1.3756                  | 1.4502           | 0.7766       | 0.8002   | 0.8196          |
| 0.80         | 0.6031                   | 0.6634      | 0.7104                  | 0.7473           | 0.5180       | 0.5334   | 0.5460          |
| 0.85         | 0.4045                   | 0.4440      | 0.4747                  | 0,4966           | 0.3092       | 0.3182   | 0.3256          |
| 0.90         | 0.2426                   | 0.2699      | 0.2639                  | 0,2960           | 0.1393       | 0.1433   | 0.1465          |
| 0.95         | 0.1100                   | 0.1202      | 0.1261                  | 0.1344           | 0.0603       | 0.0826   | 0.0644          |
| 0.97         | 0.0635                   | 0.0694      | 0.0739                  | 0.0775           | 0.0257       | 0.0265   | 0.0270          |
| A 40         | 0.0204                   | 0.0223      | 0.3237                  | 0.0318           | ~~~/         | -,       |                 |

# Appendix B

Curves of  $c_{T_i} - \eta_i - \lambda$  for 3,4,5 and 6 bladed propellers



PIG 1  $C_{T_{ij}} \sim \eta_1 \sim \lambda$  Relationship for THRES-BLANCS Propolitors

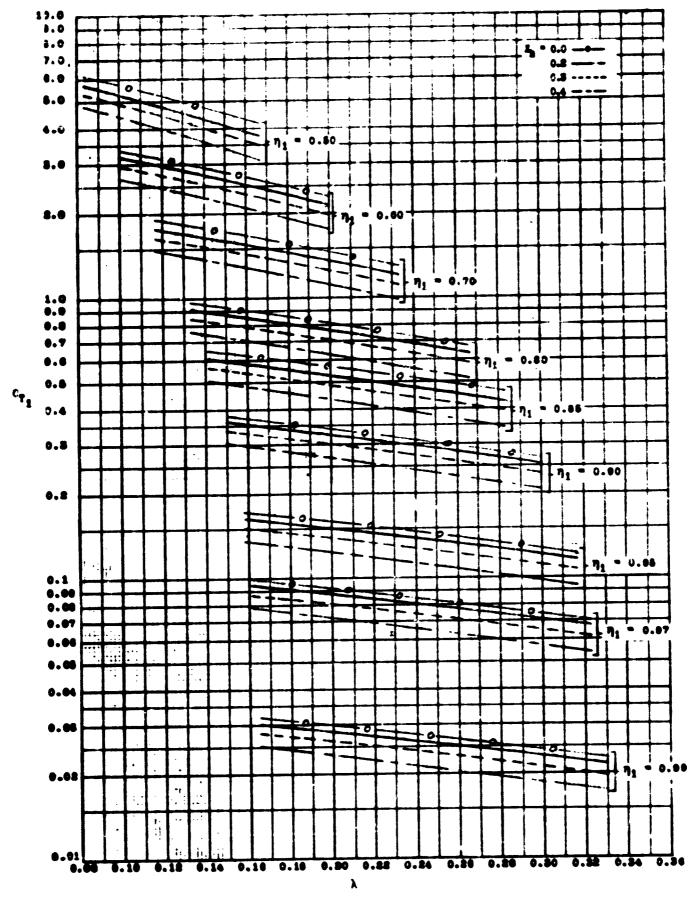
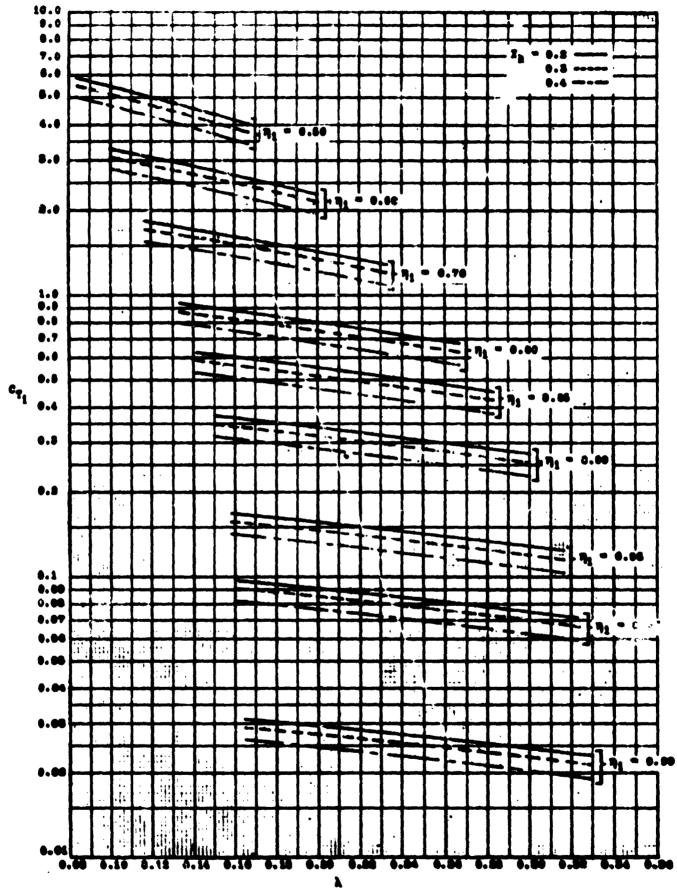
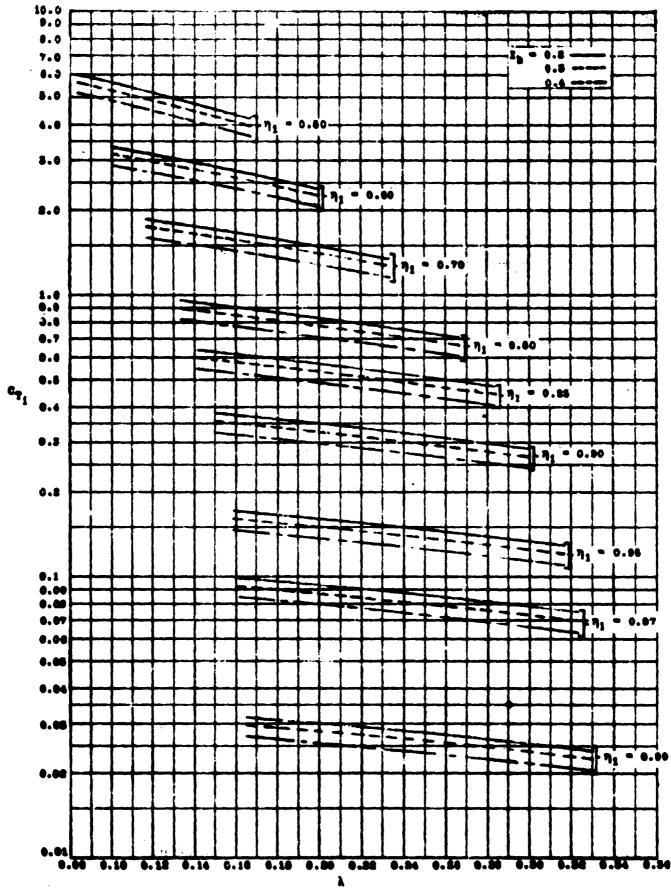


Fig. 2.  $c_{\tilde{\gamma}_1} = \eta_1 = \lambda$  Relationship for FOUR-SLADED Propellors



P10 8  $c_{\gamma_1}$  -  $\eta_1$  -  $\lambda$  holoslosomip for PTV0-OLASED Propolloro



710 6  $c_{T_{\frac{1}{2}}}$  -  $\eta_{\frac{1}{2}}$  -  $\lambda$  Polationomia for SIZ-BLANCO Propollers

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